On the Weakening of Weathered Window Glass and Its Effect on Human Impact Resistance: Two Fatality Case Studies

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Abstract

Older buildings face a heightened safety risk at windows because weathered glass is weakened against human impact. Magnifying this hazard is the additional factor that many buildings predate building codes that specify safety glass at floor level.

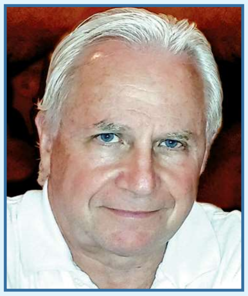
These risk factors came together tragically in two separate fatality matters studied by the author, who served as an expert witness. The fatalities were a two-year-old boy and a 30-year-old woman. In both cases, the victims broke through weathered window glass and fell from heights to their deaths.

To understand the extent to which glass weathering was a factor in the deaths, the author adapted a safety glazing test method to find the impact force at which the glass was no longer a fall barrier. Weakening of the weathered glass was found to be significant.

Test results, building codes, safety glazing codes, historical approaches, and ASTM E1300 will be discussed.

Speaker

Mark Meshulam



MARK MESHULAM joined Builders Architectural, an Illinois window and glass company, in 1981. His 30-year career included positions as sales engineer, VP of operations, and engineering director, and he assumed ownership in 1992. Meshulam supervised shop drawings and testing in field and laboratory mock-ups, overseeing installation of millions of square feet of products. He also provided consultation, testing, and expert work in a separate consulting division. In 2010, Meshulam launched Mark Meshulam LLC, providing consultation, testing, and expert work in the field of building façades. Meshulam has written 80 industry articles, which are posted at ChicagoWindowExpert.com.

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INTRODUCTION

Occupants of older buildings face a heightened safety risk at windows because weathered glass is weakened against human impact. Magnifying this hazard is the additional factor that some buildings predate building codes that specify safety glazing at floor-level window glass. Some building operators believe that they are “grandfathered” so that they do not need to retrofit floor-level windows with safety glass.

This paper will present two fatality cases wherein victims accidently came in contact with weathered window glass and unexpectedly broke through the glass to their deaths. The author served as expert witness on behalf of the plaintiffs in both lawsuits that followed the deaths. Part of that work included the performance of impact testing on exemplar glass from the sites, and other glass types for comparison. Building conditions, applicable codes and standards, and test results will be presented.

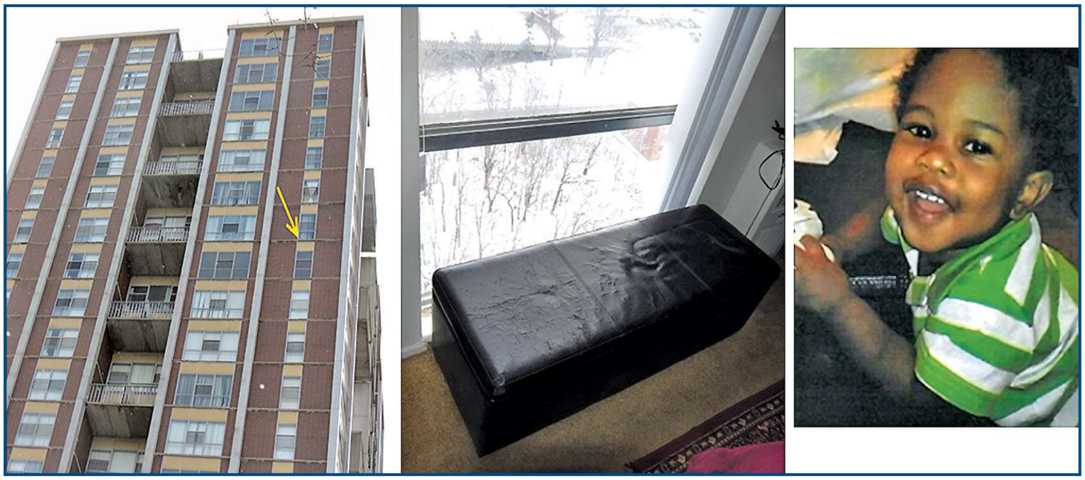


Figure 1 – Left: Crystal Tower Apartments with arrow indicating incident window. Center: View from inside of incident window. Right: Alijah Glenn.

Figure 2 – Left: The W Hotel, Atlanta. Center: Incident window. Right: LaShawna Threatt.

THE VICTIMS AND INCIDENTS

The victims were 2-year-old Alijah Glenn and 30-year-old LaShawna Threatt.

Alijah Glenn (*Figure 1*, right) was playing with his 3-year-old brother in their grandmother’s 17th-floor apartment (*Figure 1*, left) in Crystal Tower Apartments, East Cleveland, Ohio, on January 13, 2014. He placed himself in a narrow space between a nearby ottoman and a floor-level window (*Figure 1*, center). He broke through the monolithic non-safety glass and fell to his death. The only eyewitness was his brother. The family’s civil suit against the property settled prior to trial.

LaShawna Threatt (*Figure 2*, right), a model and mother of a daughter, was celebrating her 30th birthday on May 27, 2011, in the W Hotel in the Midtown neighborhood of Atlanta, GA (*Figure 2*, left). After dinner, a small group of friends came up to Threatt’s tenth-floor hotel room to continue the celebration. Threatt and her friend Cierra Williams were joking while crouching with their backs to the floor-level window, which was glazed with monolithic non-safety glass (*Figure 2*, center). They leaned against the glass, and it unexpectedly broke. Both women fell backward through the glass and fell to the sloped glass skylight eight floors below. Threatt died. Williams rolled down the skylight, fell off its edge, and dropped an additional distance to the pavement. She survived with permanent injuries. There were four eyewitnesses to the incident. The family’s civil suit against the Hotel was settled prior to trial.

THE INCIDENT GLASS

In both cases, the glass that unexpectedly gave way was weathered, floor-level, monolithic non-safety glass. The glass at Crystal Tower was $\frac{1}{8}$-in.-thick clear annealed glass that was 39 years old when the incident occurred. The glass at the W Hotel was $\frac{3}{16}$-in. bronze annealed glass that was 37 years old at the time of the incident (*Figure 3*).

BUILDING CONDITIONS

At Crystal Tower, in the eight years prior to the incident, 50 lites of glass had

	Threatt	Glenn
Date of construction	1974	1975
Date of Incident	5/27/2011	1/13/2014
Age of glass at incident	37 years	39 years
Glass type	3/16" bronze annealed	1/8" clear annealed
Glass size	46.5" x 38.5"	44" x 24.5"
Glass area	12.4 sf	7.5 sf
Window type	Fixed	Fixed
Placement of glass	Floor level	Floor level

Figure 3 – Incident information.

been replaced. Broken glass could be seen littered on the grounds at the base of the building. Cracked glass could be seen in some of the windows. Poor maintenance was also evident when viewing the façade, which consisted of exposed concrete slab edges with brick infills. The slab edges were so deteriorated that large chunks had fallen off, exposing rusty rebar.

At the W Hotel, between 2008 and 2012, 102 glass lites had been replaced due to breakage. It was common that hotel guests were charged for the damage. The glass had been cap-sealed on the outside as a part of a prior renovation. On the inside, drive-in glazing gaskets were shrunk back significantly. During inspection of the incident hotel room, one of the other glass lites in the same incident room was found to be cracked.

PRIOR STUDIES OF WEATHERED GLASS

There have been numerous studies of the diminished strength of weathered glass. Many of them were done in the 1980s as doctoral projects of luminaries in the glass industry who are still active today. For instance, Abiassi[1] in 1981 used uniform ramped air pressure to test 20-year-old glass and compare it with new glass (*Figure 4*).

RELATED CODES – GLAZING NEAR A WALKING SURFACE

Crystal Tower was built in 1975. The construction was governed by the Ohio Building Code. There were no subsequent major renovations. In 1979, Ohio adopted the Building Officials Code Administrators (BOCA) codes. Then in 2002, Ohio adopted the International Building Codes (IBC). At the date of this writing, the legacy Ohio Building Code had not been located. The BOCA codes and IBC codes require safety glazing near a walking surface (*Figure 5*).

The W Hotel was built in 1974. The 1973 Southern Standard Building Code (SBC) governed during construction. In that code, safety glass was required near walking surfaces; however, safety glass was not used. There was a major renovation that occurred when the 2006 IBC was in effect. The IBC also required safety glazing near walking surfaces, but safety glass was not retrofitted during the construction, and the original glass remained in place.

RELATED CODES - SAFETY GLAZING CODES

In the 1970s it became recognized by the U.S. Consumer Products Safety Commission (CPSC) that extensive and serious injuries related to accidental human contact with broken glass were occurring. Following a developmental effort between the CPSC and the glazing industry, the American National Standards Institute (ANSI) 16CFR1201, *Safety Standard for Architectural Glazing Materials*, became effective July 6, 1977. Extracts are below:

> The safety requirements are designed to reduce or eliminate unreasonable risks of death or serious injury to consumers when glazing material is broken by human contact.
>
> (i) Lacerations, contusions, abrasions, and other injury or death resulting from walking or running into glazed doors or sliding glass doors believed to be open or glazed panels mistaken as a means of ingress or egress, or pushing against glazing material in doors or glazed panels in an attempt to open a door.
>
> (ii) Lacerations, contusions, abrasions, and other injury or death resulting from accidentally falling into or through glazed doors, sliding

Author	Glass Source	Year	Glass type	Age of glass (years)	Size (in)	Exposure	Type of test pressure	Side in tension	Number of samples	Reference	Average failure pressure (psf)
Abiassi	New	1981	1/8" sheet glass	0	16.25 x 19.75	NA	Uniform, ramped air pressure, 60-second duration	tin side	11	P82 TABLE 18	525
								air side	12	P83 TABLE 14	492
	Dallas			20		E		weathered side	11	P80 TABLE 16	323
								unweathered side	11	P81 TABLE 17	226

Figure 4 – Abiassi results (1981).

HAZARDOUS CONDITIONS REQUIRING SAFETY GLAZING NEAR WALKING SURFACES

BOCA 1996; IBC 2000, 2003, 2006, 2009, 2012

7. Glazing in an individual fixed or operable panel, other than in those locations described in preceding Items 5 and 6, which meets all of the following conditions:
   - 7.1. Exposed area of an individual pane greater than 9 square feet (0.84 m^2);
   - 7.2. Exposed bottom edge less than 18 inches (457 mm) above the floor;
   - 7.3. Exposed top edge greater than 36 inches (914 mm) above the floor; and
   - 7.4. One or more walking surfaces within 36 inches (914 mm) horizontally of the plane of the glazing.

Exception: Safety glazing for condition number 7 is not required for the following installations:

1. A protective bar 1$^1/_2$ inches (38 mm) or more in height, capable of withstanding a horizontal load of 50 pounds per linear foot (730 N/m) without contacting the glass, is installed on the accessible sides of the glazing 34 inches to 38 inches (864 mm to 965 mm) above the floor.

Figure 5 – Typical code wording that requires safety glazing near walking surfaces.

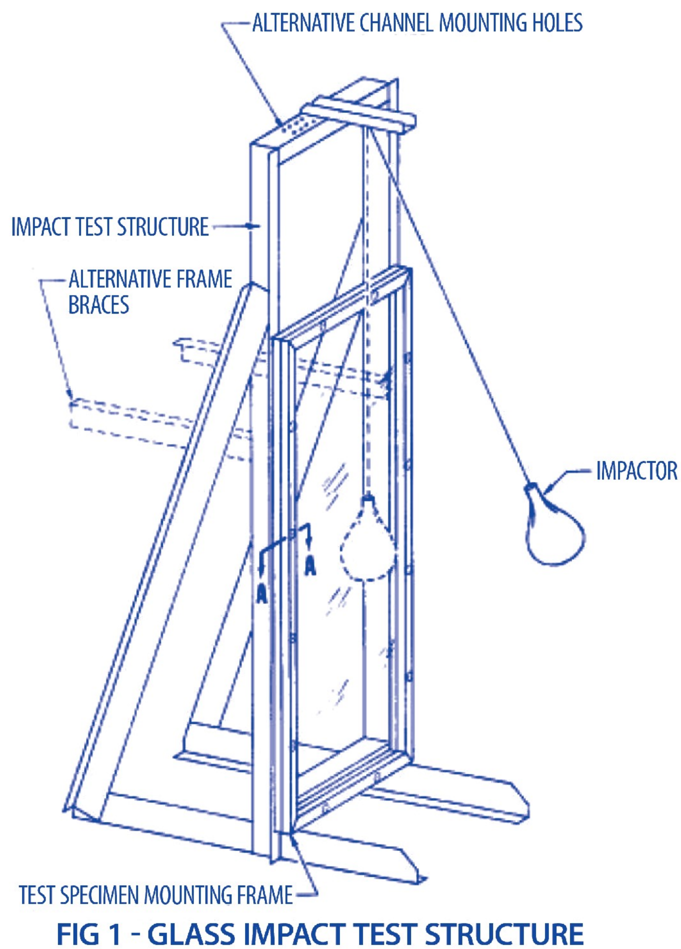


Figure 6 – Extract from 16 CFR 1201 – Glass impact test structure.

glass doors, glazed panels, bathtub doors and enclosures, and shower doors and enclosures. (underline added)

Note that this code does not specifically address what might happen to someone who falls through glass from heights; therefore, there is no wording that shows an intention to have the glass act as a barrier against falling through the glass. Neither CPSC nor ANSI include glass near a walking surface in the list of hazardous conditions.

16 CFR 1201 and ANSI Z97.1 are U.S. government and industry standards, respectively. They offer similar test methods for the certification of safety glazing. The methods use an impactor (*Figure 6*) for providing a representation of human contact to the glass. The impactor consists of a punching bag filled with steel shot, so that the assembly weighs 100 lbs. The impactor is suspended from a cable and positioned so that it hangs just near the surface at the center of the glass. Then it is pulled back a distance so that the vertical component (the ball drop height) of its travel is equal to either 18 in. (1.5 ft.) or 48 in. (4 ft.). When it is released, it travels toward the glass and impacts the glass at a force that is measured in ft.-lbs.

Since the impactor is 100 lbs., a ball drop height of 18 in. will deliver an impact force of 150 ft.-lbs (100 lbs. x 1.5 ft.). A ball drop height of 48 in. will deliver 400 ft.-lbs of impact (100 lbs. x 4 ft.). The 18-in. ball drop height is used for glass that is 9 sf or less. The 48-in. height is used for larger glass.

Tempered glass and laminated glass can both be tested and certified to meet safety glazing standards, whereupon they are deemed "safety glazing." However, the mechanism by which they achieve the added safety when broken by human contact is different.

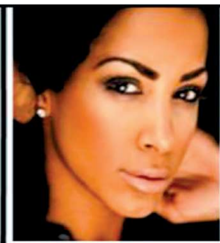
Tempered glass achieves the greater measure of safety by breaking into small particles, or cubes, thereby reducing the severity of lacerations. Laminated glass is held together by the plastic interlayer, so it is safer by virtue of containing potentially dangerous shards.

During testing, both glass types are impacted one time at the required impact force. Non-breakage constitutes a passing test. When broken, the tempered glass must break into small particles. This is defined such that the weight of the ten largest particles must not exceed the weight of 10 square inches of glass. Laminated glass is turned horizontal after impact. A 4-lb., 3-in.-diameter steel ball is placed on the glass. If it does not pass through the glass for 1 second, the test is passed.

RELATED CODES – WINDOW OPENING CONTROL

These codes, supported by ASTM F2090, require that window openings be limited such that a 4-in.-diameter ball cannot pass through if the windowsill is within either 24 or 36 in. from the interior floor when the exterior sill height exceeds 72 in. Window guards can also be used.

Glass Strength for Wind Loading



		Code Req'mt	Glass Capability	Code Req'mt	Glass Capability
Wind Load Chart*	60 sec	32 psf	65 psf	Not Available	53 psf
ASTM E1300-94			45 psf		34 psf
ASTM E1300-98/00					
ASTM E1300-02/03	3 sec		60 psf		46 psf
ASTM E1300-04					
ASTM E1300-09					

Max: Maximum wind load which would be met by the glass

* Safety factor of 2.5

All use 8/1000 as maximum probability of breakage at first occurrence

All assume rigid edge support

Figure 7 – Glass strength requirements according to various standards and the theoretical strength capabilities of the incident glass.

WIND LOAD

In the Threatt matter, whether measured using the legacy wind load charts of the day or any of five versions of ASTM E1300, the incident glass met wind load. In the Glenn matter, the early Ohio Building Code is not available, but the incident glass would likely have met the wind load requirements (*Figure 7*).

WEATHERING BASIS OF ASTM E1300

ASTM E1300 is built upon a probability model first created by Weibull[2] in 1939, and developed by Beason.[3] It is a calculus formula that expresses glass strength through the use of two surface strength parameters, m and k. In the formulas that underlie glass strength, the parameters used represent glass that has undergone in-service conditions for approximately 20 years (*Figure 8*). The glass that is the subject of this study was still in service at nearly twice that age.

Basis of ASTM E1300

- Weibull (1939) 2-parameter probability of failure for brittle materials

$$P_f = 1 - \exp(-B)$$

- Beason's formula for risk function "B" in the formula above for glass plate:

$$B = k \int_0^a \int_0^b \left[c(x,y)\,\sigma(x,y) \left\{ \frac{t_d}{60} \right\}^{1/16} \right]^m dx \cdot dy$$

- m and k are surface strength parameters

$$B = k \int_0^a \int_0^b \left[c(x,y)\,\sigma(x,y) \left\{ \frac{t_d}{60} \right\}^{1/16} \right]^m dx \cdot dy$$

In development of the non-factored load charts presented in Figs. 1-12 it was assumed that m is equal to 7 and k is equal to 2.86×10^{-53} N^{-7} m^{12} (1.365×10^{-29} $in.^{12}$ lb^{-7}). These flaw parameters represent the surface strength of weathered window glass that has undergone in-service conditions for approximately 20 years.

Figure 8 – Formulaic bases for the glass strength calculations embedded in ASTM E1300.

WILL SAFETY GLAZING ACT AS A BARRIER AGAINST FALLS THROUGH GLASS?

Whereas many codes require safety glazing in glass near walking surfaces, there is no statement that the safety glazing is intended to act as a barrier against human falls.

Despite this absence of intention, our research has demonstrated that both tempered and laminated glass can make a significant contribution toward preventing people from falling through the glass. Tempered glass accomplishes this by being more difficult to break than annealed glass. Laminated glass acts as a fall barrier by holding together even if the glass is broken.

IMPACT STUDIES OF WEATHERED ANNEALED GLASS

In both fatality cases, there was a need to determine the extent to which the window glass was weakened through weathering, and to also understand what safety benefits might have been realized through the use of safety glazing. A definition was created: "breakthrough." This is defined as the lowest impact force delivered to the glass that causes the glass to cease to act as a barrier against human falls.

The author based test methodology upon existing safety glazing methods to the greatest possible extent. To that end, the use of a 100-lb. impactor was chosen because it already has industry acceptance with regard to representing human contact. It also has a simple way to calculate the amount of impact delivered to the specimen because the impact force is simply derived from the ball drop height.

The method for securing the glass to the test frame during testing was taken directly from the safety glazing standards, with the exception that the frame was sized for the exact glass size that was involved in the respective incidents. By contrast, prior methods for measuring weathered glass strength, such as ring-on-ring

DROP HEIGHTS			
TRIAL #	DROP HEIGHT (IN.)	IMPACT LOAD (FT.-LBS.)	NOTES
1	3	25	Used for weathered glass only in Threatt testing; used for all glass in Glenn testing
2	6	50	
3	9	75	Used for Glenn testing only
4	12	100	
5	18	150	CATEGORY I PER 16 CFR1201 FOR GLASS 9 SF OR LESS
6	24	200	
7	30	250	
8	36	300	
9	42	350	
10	48	400	CATEGORY II PER 16 CFR1201 FOR GLASS GREATER THAN 9 SF
11	54	450	Used in Threatt testing only

Figure 9 – Ball drop heights and corresponding impact loads.

testing, have relied upon cutting the glass to a smaller, standardized size.

Exemplar glass removed from the incident sites was tested, along with the same size of new annealed glass, tempered glass, and laminated glass. The glass types were tested in cycles rather than being tested by group.

Thanks to a grant provided by the attorney client in the Threatt matter, the author was able to practice before the actual testing took place. This was worthwhile because in order to determine the break-through force of the glass, there would need to be multiple impacts ramped up from small to large. The practice testing helped develop the succession of impact forces that were used. When some annealed glass in the Threatt matter was found to break through on the first impact (6-in. drop, 50 ft.-lbs.), a lower impact force (3-in. drop, 25 ft.-lbs.) was added for the weathered glass in the Threatt testing and for all glass in the Glenn testing (*Figure 9*). All weathered glass in both matters matter broke on the first impact of 25 ft.-lbs.

IMPACT TESTING – THREATT

Results of Threatt impact testing are shown in *Figure 10*.

The weathered glass broke through at the lowest impact force, only 25 ft.-lbs. The new annealed glass averaged significantly higher break-through values than the weathered sample (158.3). This dramatically demonstrates the loss of glass strength through weathering, but the sample size was limited. Three of the six new annealed lites tested broke through at 100 ft.-lbs. or less, so replacing weathered annealed glass with new annealed glass would not be a good choice.

The laminated glass produced the highest break-through values (average 370 ft.-lbs.) while showing consistent results overall. The lowest break-through value of laminated glass was 200 ft.-lbs.

Tempered glass also produced high average break-through values (316.7 ft.-lbs.), however it was less consistent. One lite broke through at only 100 ft.-lbs.

Impact Test Results - Threatt															
Specimen Designation	Test Date	Thickness (inches)	Drop Height (Inches)										Total Number of Impacts	Drop Height at Break Through (inches)	Corres-ponding Impact Energy (ft.-lbs.)
			3	6	12	18	24	30	36	42	48	54			
New 1/4" (.238") Laminated Glass Glass Size 46 1/2" x 38 1/2"															
A1	5/22/2013	1/4"	--	C	--	--	--	C	--	BT	--	--	3	42	350
A2	5/22/2013	1/4"	--	C	C	C	BT	--	--	--	--	--	4	24	200
A3	5/23/2013	1/4"	--	--	--	--	--	--	--	--	BT	--	1	48	400
A4	5/23/2013	1/4"	--	--	--	--	--	--	--	--	C	BT*	2*	54*	450*
A5	5/23/2013	1/4"	--	--	--	--	--	--	--	--	C	BT*	2*	54*	450*
												Average:	**2.4**	**44.4**	**370**
New 3/16" (.184") Tempered Glass Glass Size 46 1/2" x 38 1/2"															
B1	5/22/2013	3/16"	--	N	N	N	N	BT	--	--	--	--	5	30	250
B2	5/22/2013	3/16"	--	N	N	N	N	N	N	BT	--	--	7	42	350
B3	5/22/2013	3/16"	--	N	N	N	N	N	N	N	N	BT	9	54	450
B4	5/23/2019	3/16"	--	N	BT	--	--	--	--	--	--	--	1	12	100
B5	5/23/2019	3/16"	--	N	N	N	N	BT	--	--	--	--	5	30	250
B6	5/23/2019	3/16"	--	N	N	N	N	N	N	N	N	N	10*	60*	500*
												Average:	**6.2**	**38.0**	**316.7**
New 3/16" (.184") Annealed Glass Glass Size 46 1/2" x 38 1/2"															
C1	5/22/2013	3/16"	--	N	N	N	BT	--	--	--	--	--	4	24	200
C2	5/22/2013	3/16"	--	N	BT	--	--	--	--	--	--	--	2	12	100
C3	5/22/2013	3/16"	--	N	N	N	N	N	BT	--	--	--	6	36	300
C4	5/23/2019	3/16"	--	N	N	N	BT	--	--	--	--	--	4	24	200
C5	5/23/2019	3/16"	--	N	BT	--	--	--	--	--	--	--	2	12	100
C6	5/23/2019	3/16"	--	BT	--	--	--	--	--	--	--	--	1	6	50
												Average:	**3.2**	**19.0**	**158.3**
Weathered 3/16" (.187") Annealed Glass from W Hotel, Atlanta Glass Size 46 1/2" x 38 1/2"															
D1	5/23/2013	3/16"	BT										1	3	25
												Average:	**1**	**3**	**25**
Key:	N = No Break/Cracks			C = Cracks Appear; No Break Through							BT = Break Through				
* = Assumed Next Round Will Break Through															

Figure 10 – Results of Threatt testing.

Impact Test Results - Glenn

Specimen Designation	Test Date	Thickness (inches)	Drop Height (Inches) 3	6	9	12	18	24	30	Total Number of Impacts	Drop Height at Break-through (inches)	Corresp. Impact Energy (lbf.-ft.)
New 1/4" Laminated Glass (A)												
A1	09/15/15	0.246	N	N	N	N	C	C	BT	7	30	250
A2	09/15/15	0.243	N	N	C	C	BT	--	--	5	18	150
A3	09/15/15	0.241	N	N	C	C	BT	--	--	5	18	150
A4	09/16/15	0.241	N	N	C	C	C	BT	--	6	24	200
A5	09/16/15	0.241	C	C	C	C	C	BT	--	6	24	200
									Average:	5.8	22.8	190
New 1/8" Tempered Glass (B)												
B1	09/16/15	0.123	N	N	BT	--	--	--	--	3	9	75
B2	09/16/15	0.124	N	N	N	N	N	BT	--	6	24	200
B3	09/16/15	0.122	N	N	N	N	BT	--	--	5	18	150
B4	09/16/15	0.123	N	N	N	N	N	N	BT	7	30	250
B5	09/16/15	0.124	N	N	N	N	BT	--	--	5	18	150
									Average:	5.2	19.8	165
New 1/8" Annealed Glass (C)												
C1	09/15/15	0.127	N	N	N	BT	--	--	--	4	12	100
C2	09/15/15	0.127	N	N	N	BT	--	--	--	4	12	100
C3	09/15/15	0.124	BT	--	--	--	--	--	--	1	3	25
C4	09/16/15	0.125	BT	--	--	--	--	--	--	1	3	25
C5	09/16/15	0.125	N	N	BT	--	--	--	--	3	9	75
									Average:	2.6	7.8	65
Weathered 1/8" Annealed Glass Removed from Building (D)												
D1	09/15/15	0.117	BT	--	--	--	--	--	--	1	3	25
D2	09/15/15	0.122	BT	--	--	--	--	--	--	1	3	25
D3	09/15/15	0.122	BT	--	--	--	--	--	--	1	3	25
D4	09/16/15	0.117	BT	--	--	--	--	--	--	1	3	25
D5	09/16/15	0.121	BT	--	--	--	--	--	--	1	3	25
									Average:	1	3	25

Figure 11 – Results of Glenn testing.

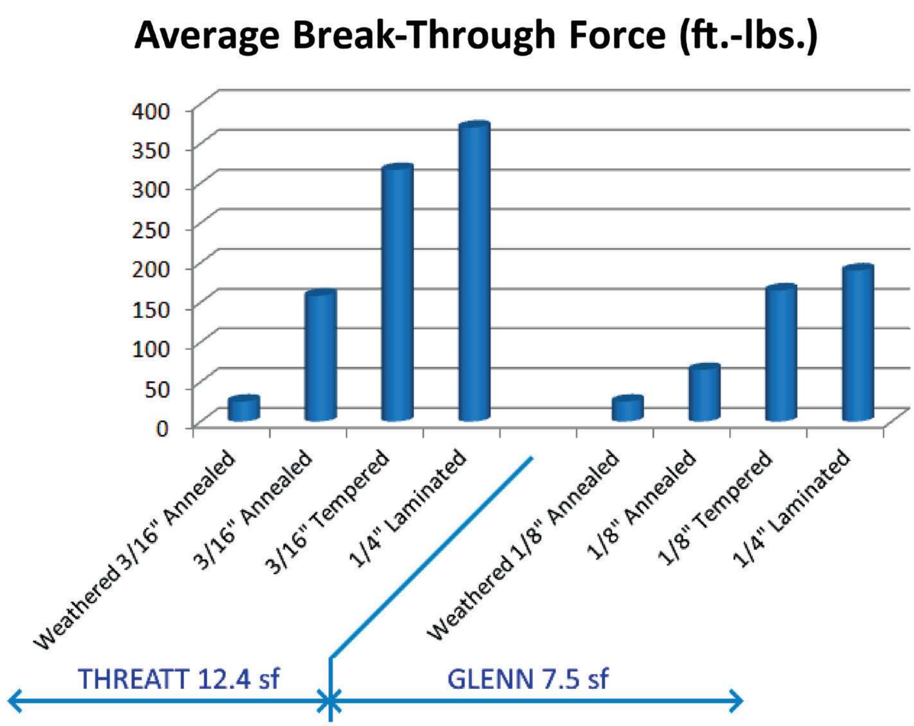


Figure 12 – Average break-through forces for each glass type, both incidents.

IMPACT TESTING – GLENN

Results of Glenn impact testing are shown in *Figure 11*.

All five weathered samples (D) broke through on the first impact of a 3-in. ball drop (25 ft.-lbs.). Given this, it is possible that the weathered glass might have broken through at even lower impact forces.

Two of the five new annealed lites (C) also broke through on their first impact, but two others broke through on the fourth impact of a 12-in. ball drop (100 ft.-lbs.).

The difference in average break-through force between D and C may be the truest and simplest measure of weathering. An average of 65 ft.-lbs. for C compared with 25 ft.-lbs. for D implies that the new annealed glass is, on average, 2.6 times stronger than the weathered glass against human impact. While it is a significant improvement, replacing weathered annealed glass with new annealed glass would not be the best choice.

New ⅛-in. tempered glass (B) shows a marked improvement in resistance to break-through. It took an average of 5.2 successively greater impacts, with an average impact force of 165 ft.-lbs. to achieve break-through.

New ¼-in. laminated glass (A)—the thinnest commonly available laminated glass—gave the best performance with regard to break-through resistance. Even though it might have cracked at lower impact forces, it broke through at an average of 5.8 impacts at an average of 190 ft.-lbs. This performance was observed to be dependent upon the strength of the edge connection. If the glass edges were held more loosely, the "wet blanket" of glass would have surely evacuated the opening at lower force values.

IMPACT TESTING SUMMARY

A summary of impact testing results for both incidents is presented in *Figure 12*.

Test results for both incidents were consistent in demonstrating that weathered glass is severely degraded over time with regard to impact resistance. Further, the safety glasses (tempered and laminated) were found to be far superior against break-through when compared with annealed glass.

CONCLUSION

It is hoped that this information will sensitize building professionals to dangers posed by weathered glass in buildings, especially when it is non-safety glass at floor level. Armed with this knowledge, building inspectors should be better equipped to warn clients that dangerous conditions exist. Code writers are encouraged to strengthen language about requiring safety glass to be retrofitted in older buildings and disallowing the "grandfathering" of unsafe conditions. Industry engineers who continue to develop glass strength calculations as exist in ASTM E1300 should be alerted that the 20-year weathering timeframe embedded in the strength calculations may be insufficient because glass is often used in buildings far beyond 20 years.

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